DIAGNOSTICS UPDATE OF THE TAIWAN LIGHT SOURCE

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Abstract

Diagnostics of the 1.5 GeV Taiwan Light Source (TLS) have been continuously upgraded since its operation started in 1993. The BPM electronics of the Taiwan Light Source (TLS) have been upgraded to Libera Brilliance in August 2008 to improve performance and functionality. Orbit feedback has also been migrated to a fast orbit feedback system to enhance orbit stability. Commercial photon BPM electronics were tested recently. A new-generation bunch-by-bunch feedback processor to improve beam stability was tested. Post-mortem diagnostic tools were gradually added to clarify reasons for beam trip. These upgrades contributed to improving beam quality and machine availability greatly.

INTRODUCTION

TLS was dedicated to the user in 1993. There have been several major upgrades recently, including a 2005 superconducting-RF upgrade and a 2008 BPM upgrade. The SRF system upgrade is improving beam quality and providing sufficient RF gap voltage for high current operation. Currently, the machine is operated at 1.5 GeV, 360 mA top-up injection. The BPM system upgrade also provides good diagnostics, which are essential to good quality machine operation. In the meanwhile, along with BPM upgrade, the orbit feedback system has also migrated to a fast orbit feedback system to enhance orbit stability, which is extremely important for a modern synchrotron light source.

To further improve beam availability, a beam trip event diagnostic has been deployed in the TLS. These diagnostic tools can clearly reveal and track causes of the beam trips and provide enough information to aid maintenance.

Libera Photon provides a good integration environment to correlate electron and photon beam motion. An earthquake detector has been installed lately as well, to record trip events caused by quakes. A new generation bunch-by-bunch feedback processor is also tested. All of these efforts above will be addressed respectively in the following sections.

CONTROL ENVIRONMENT ADAPTATION

The EPICS toolkits were chosen as the control system frameworks for the new 3 GeV synchrotron light source (Taiwan Photon Source, TPS). It has been decided that the control system for TLS should support both its existing control environment and EPICS as an upgrade-maintenance strategy to save resources and minimize development of the existing control system. New devices and/or replacement of the obsolete system are being considered to employ the EPICS directly. Gateways are implemented to exchange data between both environments and let them operate side by side. Modification for the control system has continuously proceeded during the last several years. New technology and improved maintenance are consequent advantages, along with manpower savings.

NEW BPM SYSTEM

Libera Brilliance [1] is employed to replace the existing BPM electronics for the TLS. Its integration started from 2007 until finished in August 2008 [2,3]. It was gradually deployed and performed without interfering with routine operation. There are 59 Libera Brilliances online, operating for more than one and half year. Adequate long-term reliability has been achieved.

Slow and Fast Data

New BPM system delivers high precision data at a 10 Hz rate for control system access with 0.1 μm resolution. The new BPM also delivers 10 kHz position data for fast orbit feedback applications and analysis applications with 0.2 μm resolution.

Turn-by-Turn Data and Post-mortem Data

Turn-by-turn data is also provided by Libera Brilliance. It is useful for accelerator physics study and helps to reveal fast beam motion such as beam excitation caused by the kicker and septum [2]. Post-mortem buffers as long as 256 kilosamples give turn-by-turn data before beam trip; this has proved to be a powerful diagnostic tool [2].

Some Observations by the New BPM System

The new BPM system unveils some effects that were not easily discovered systematically in the old BPM system. Several examples are summarized below.

A power supply with defects in its regulator might cause some 60 or 120 Hz strong perturbation. Fig. 1 is an example, showing a beam orbit motion that has 120 Hz power line noise. With the aid of the new BPM system, this perturbation was shown to come from a compensated corrector power supply of the insertion Device U9.

The leakage field of septum and kicker will also cause an orbit excursion and will have effects on the optical-radiation strength and precision. The experimental station should exclude the sampled data during injection by means of the provided gating signal. During the long shutdown of Spring 2010, mu metal was adopted to wrap the chamber and shield it from the field leakage. Figs. 2 and 3 show the orbit distortion caused by septum leakage before and after chamber shielding. The excursion is about half what it was before chamber shielding.

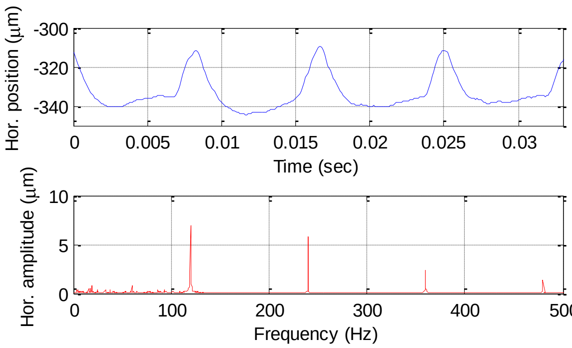


Figure 1: Orbit motion due to the ill power supply for undulator U9 end corrector.

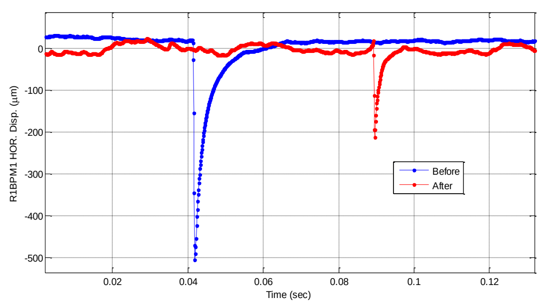


Figure 2: Orbit excursion at R1BPM1 caused by septum leakage before and after mu-metal was added.

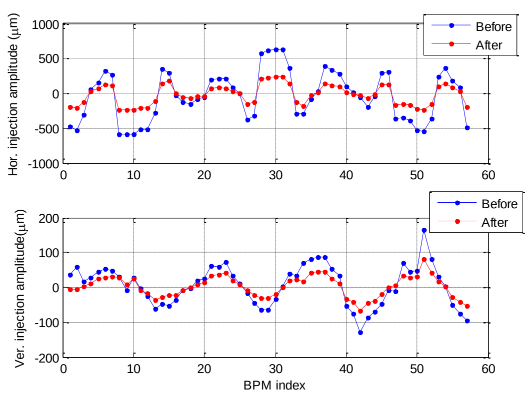


Figure 3: Amplitude of orbit distortion caused by septum leakage before and after septum shielding.

NEW ORBIT FEEDBACK SYSTEM

The infrastructure of the new orbit feedback system is shown in Fig. 4. The orbit controls for the horizontal and vertical plane are separated, which is different from the old version and increases flexibility and computation power. The reflective memory is employed to share fast orbit data without consuming extra CPU resources, and supports data acquisition for other subsystems. Libera Brilliance units are grouped together by a redundant multi-gigabit links via the LC optical links and copper "Molex" cables. This link supports data collecting among all Libera Brilliance units, assembling large packets via FPGA and sending the gathered data as unidirectional User Datagram Protocol (UDP) packages via Gigabit Ethernet. It reduce packet numbers in the network drastically, and eliminates jitter and package loss [3].

There are several kinds of corrector magnets installed in the TLS due to historical reasons. They have different system responses. To understand the compound response of the power supplies, correctors, vacuum chamber and the stored beam, pseudo-random binary sequence (PRBS) excitation is employed to measure system response and latency [3]. The responses of these correctors differ from each other. The bandwidth of some correctors can achieve to 80 Hz, but others may be below 30 Hz. Choosing the proper correctors for FOFB through measurements around the whole storage ring is thus necessary.

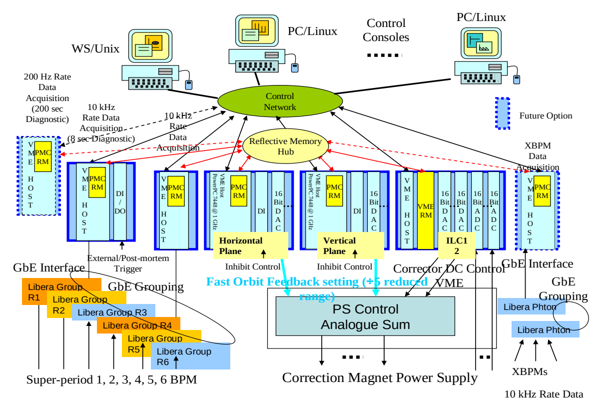


Figure 4: Infrastructure of the new orbit feedback system and the related subsystems.

The latency, which affects system performance, has been estimated. The I/O latency time is around 500 μs. Processing latency of the data acquisition and computation is the sum of several parts. Transfer BPM data, rearrangement and scaling takes around 40 μs; $S^{-1}U^{T}$ matrix (response matrix $R=USV^{T}$) and PID computation around 60 μs; V matrix computation and DAC settings 20 μs. The whole feedback loop takes about 120 μs. It implies that we can push feedback sampling frequency from the current 1.25 kHz to a higher frequency, under constrains of the current orbit feedback infrastructure, which is implemented in an economic way. The overall latency is about 620 μs; that includes calculation, chamber eddy current effect, BPM reading and corrector setting delay, etc.

Singular value decomposition (SVD) is used to invert the mapping of corrector excitation and orbit response in the feedback correction algorithm. To obtain a stable solution, Tikhonov regularization is also adopted.

The bandwidth and performance of FOFB were measured and estimated by PRBS excitation. The new FOFB should suppress noise to around 50 Hz (compared to the old 6 Hz) after all components are upgraded. The new BPM performance in wideband is better than before. As a result, vertical orbit stability can be reasonably expected to be submicron from dc to 50 Hz.

The feedback system improves beam stability, as shown in Figs. 5 and 6. The standard deviation of the 10 Hz rate data of all BPM vertical plane readings can be reduced to 0.2 μm with feedback on (from 0.8 μm with it off) in the normal user mode. Horizontal and vertical orbit displacement can be less than 1 μm in SA readings.

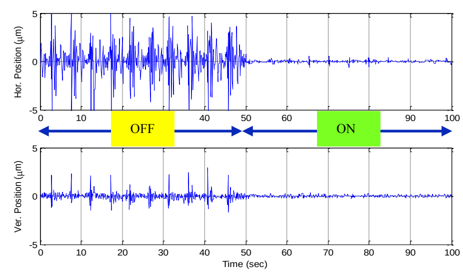


Figure 5: R6BPM7 10 Hz rate data for FOFB ON/OFF.

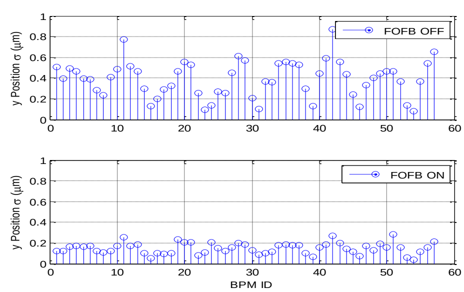


Figure 6: The standard deviation of vertical orbit displacement 10 Hz rate data between FOFB on/off.

Fig. 7 shows the R6BPM7 FA data spectrum with FOFB on and off. Orbit stability can be improved to sub-μm at this location with higher β function; thus overall RMS orbit stability should be sub-μm from dc to 50 Hz.

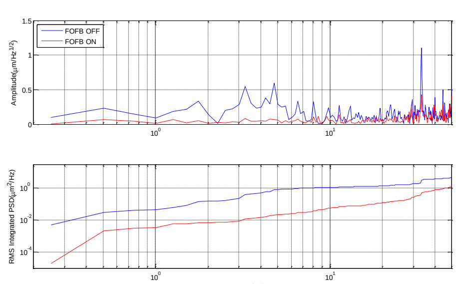


Figure 7: The spectrum and integrated PSD of R6BPM7 for FOFB on/off.

Fast insertion-device and phase changes are highly desirable. However, the old orbit feedback loop cannot effectively suppress the orbit excursion when they are faster than the limits of components and bandwidth. The wider bandwidth of the new orbit feedback loop allows increasing the motion speed. Fig. 8 (top) shows the 1 mm/s phase move of the EPU5.6. The orbit displacement is shown in Fig. 8 (bottom). It is clearly observed that the feedback loop can eliminate the orbit excursion.

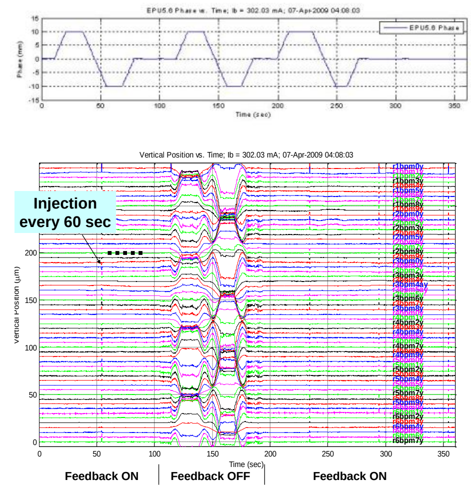


Figure 8: Effect of the new FOFB to suppress orbit excursion of 1 mm/sec phase change of EPU5.6. Top: History of the EPU5.6 phase motion at speed of 1 mm/s. Bottom: Beam position reading of all BPMs.

NEW PHOTON BPM ELECTRONICS-LIBERA PHOTON TEST

There are several kinds of photon BPMs with different designs at the beamline front ends of TLS. The electronics and data acquisition system cannot be integrated into the machine control system with the beamline or frond-end data acquisition in seamless ways due to historical reasons. Currently, one signal might split into several ways into different data acquisition systems in the current scheme. To provide better integration and efficient usage of the photon BPM, a single integrated system is under construction. The goal is to integrate with the machine control system to allow access from the beamline control system or the other clients, embedded current-to-voltage converter, embedded high performance ADCs, local computation capability, and integrated control system interface. Commercially available Libera Photon [1] satisfies all of these requirements and could integrate photon BPMs into control system seamlessly. Libera Photon combines several important components into one box.

Fig. 9 shows the observation at beamline 10. One of the vertical correctors (RCVCSPS21) was driven by a square wave. The relationship between photon BPM and Libera Brilliance reading are shown in Figs. 9 and 10. It can be observed that with FOFB off, the corrector changes will displace orbit position over 10 μm, while with FOFB on, the displacement is almost suppressed for the same corrector change. An injection transient is also clearly observed in Fig 10. The behaviour is quite similar to that of the electrical BPM in Fig. 2, where the field leakage disturbed both the electrical and the photon BPMs. Fig. 11 shows the photon displacement when the EPU5.6 phase was changed with/without FOFB. It can also be observed clearly that FOFB could almost suppress the displacement to a sub-micron level from several hundreds of microns.

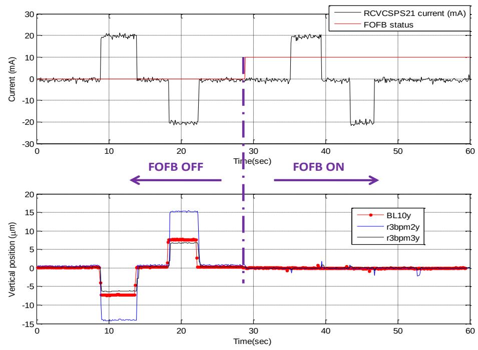


Figure 9: Beamline 10 photon BPM 10Hz reading signal related to the ring BPM.

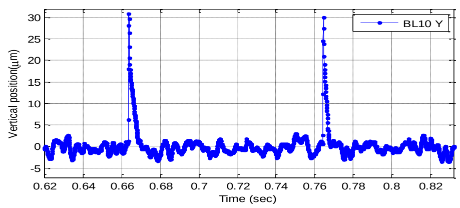


Figure 10: Beamline 10 photon BPM 10 kHz rate reading during injection.

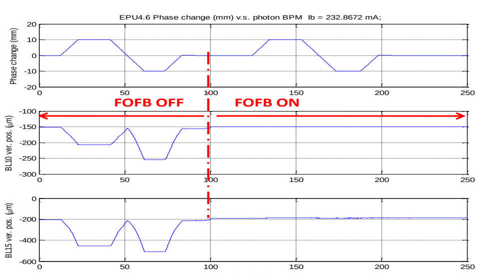


Figure 11: Beamline #10 & #11 photon BPM vertical position change vs. EPU 4.6 phase change with/without FOFB.

COMMISSIONING OF THE iGp BUNCH-BY-BUNCH SIGNAL PROCESSOR

Bunch-by-bunch feedback was deployed in 2005 in transverse and longitudinal planes [4]. To explore functionality of the new generation bunch-by-bunch feedback solutions and provide a better diagnostics, two kind of commercial products, iGp [5] and Libera Bunch-by-Bunch, are considered. Their tests are ongoing. Both systems provide good control system integration. It is planned to upgrade the bunch-by-bunch feedback system to enhance functionalities and get better performance.

Commissioning of the iGp for the longitudinal plane had taken only 20 min to enable the feedback back into operation based upon existing bunch-by-bunch feedback infrastructure. Noise floors were half those of the existing feedback system. The transverse feedback used opposite striplines in skew position as feedback kicker. A two-peak, 16-tap filter was designed as shown in Fig. 12. Instabilities of both transverse planes were suppressed successfully after 3 hours' effort. The iGP waveform interface is shown in Fig. 13. The lower right corner of Fig. 13 shows two notches in averaged spectrum corresponding to vertical and horizontal rejected betatron sideband. It can be a high resolution betatron tune monitor without exciting beam.

To explore bunch cleaning, the multibunch stored beam was killed, leaving one bunch as shown in Fig. 14. Due to low kick efficiency of the transverse excitation system, a vertical orbit bump was intentionally produced, exciting betatron motion of the unwanted bunches so they can be scraped by the ID cambers.

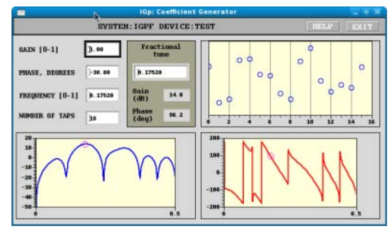


Figure 12: Two-peak, 16-taps filter for suppressing instabilities in vertical and horizontal planes using striplines installed at skew positions.

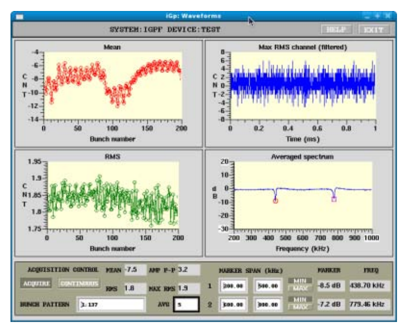


Figure 13: iGP for transverse feedback.

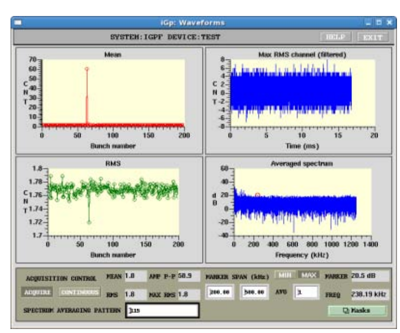
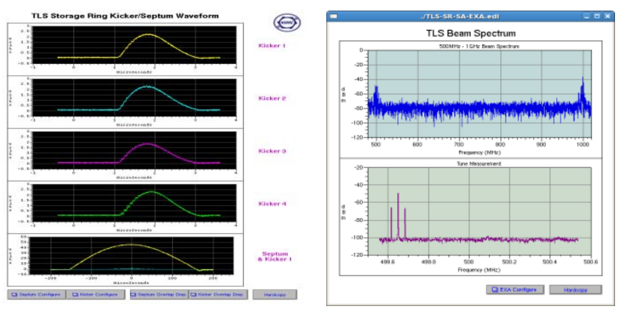


Figure 14: Bunch cleaning test; all bunches were killed except the selected bunch.

REMOTE WAVEFORM ACCESS

The TLS will share the same control room with the TPS in the future. To accommodate to this situation, remote access waveform data in the control room is necessary. Waveform data includes microwave pulses, pulse magnet current waveform, beam signals, beam spectrum, etc. EPICS support was prepared for existing Ethernet-based equipment, such as oscilloscopes, spectrum analyzers, etc., to save limited resources. A dedicated EPICS soft-IOC was set up to support these. Specific displays were developed with EDM and Matlab toolkits. Commercial EPICS scopes from ZTEC [6] were tested also. Dedicated cables to send signals to control room won't have to be built in the future. Fig. 15 (a) shows the injection pulse magnet current waveform display at the control console. The oscilloscope is installed near the pulse magnet power supplies. Fig. 15 (b) shows the beam spectrum displayed at the control console.



(a) (b)

Figure 15: (a) Storage ring injection kickers and septum waveforms. (b) Beam spectrum remote access.

POST-MORTEM DIAGNOSTICS

Besides beam stability, high availability of user service is another important issue. Analyzing the causes of trip events can help to improve reliability of subsystems and reduce troubleshooting efforts to minimize machine downtime to achieve high availability. Various diagnostics tools can capture beam trips, interlock signals of superconducting RF system, waveforms of the injection kickers, quench and interlock signals of the superconducting insertion device, and instability signals of the stored beam for post-mortem analysis, which is routine, especially for nontrivial events. Trip event analysis can point to subsystem improvements to avoid dangerous operation conditions, and consequently improve system reliability [7]. An earthquake detector has been installed to reveal the consequences of trips caused by the earthquake. The existing fault diagnostic system still cannot reveal all fault events, but the reliability of the TLS was improved by the new tools.

Fig. 16 shows what happened when an earthquake occurred at sea on the Pacific Ocean side of Taiwan. The P wave arrived at NSRRC 42 seconds later. The arrival time of the S wave lag about 30 seconds from the P wave. It means that the source is about 230 km far away form the TLS site. The SRF system trip happened 20 seconds after the S wave arrived. The trip was caused by the vibration of the Nb cavity, which resulted in deformation of the cavity and provoked a resonance frequency shift, which induced reflective power beyond the trip level.

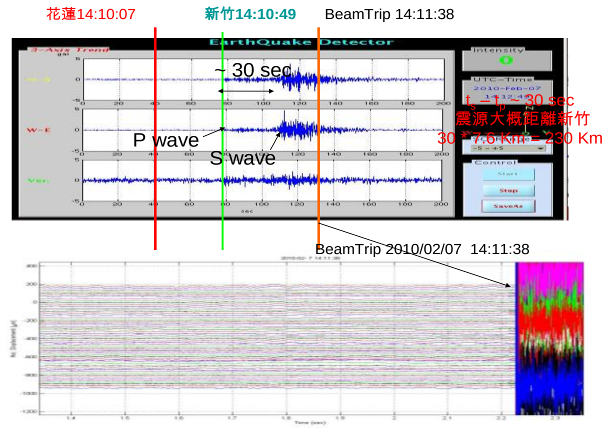


Figure 16: Earthquake signals record by the earthquake switch (top). Post-mortem data from BPM (bottom).

SUMMARY

Diagnostics of the TLS have been continuously upgraded using available resources to improve performance and avoid obsolescence. Strategies for upgrade-maintenance and minimum prepared spare parts led us to an opportunity to adopt updated technology and improve performance. Current efforts include integration of the photon BPM system, remote waveform access, new bunch-by-bunch feedback with much better functionality, and better integration with the control system.

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